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STUDY OF THE INFLUENCE OF SIZE OF A MANNED LIFTING BODY ENTRY VEHICLE ON RESEARCH POTENTIAL AND COST

FINAL REPORT

Part VIII. Alternative Approaches

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Prepared by

MARTIN MARIETTA

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Prepared Under Contract No. NAS 1-6209 by

MARTIN MARIETTA CORPORATION

Baltimore, Maryland 21203

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This document is a part of the final report on a "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Cost," conducted by the Martin Marietta Corporation, Baltimore Division, for the National Aeronautics and Space Administration, Langley Research Center, under Contract NAS 1-6209 dated April 1966. The final report is presented in eight parts:

I.	Summary	CR-66352
II.	Research Program Experiments	CR-66353
III.	Flight Performance	CR-66354
IV.	Candidate Entry Vehicle Designs	CR-66355
V.	Systems Integration	CR-66356
VI.	Research Vehicle Size Selection and Program Definition	CR-66357
VII.	Selected Entry Vehicle Design	CR-66358
VIII.	Alternative Approaches	CR-66359

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The principal contributors to the study were James McCown, Robert Schwab, Ray Sorrell and James Vaeth; Mr. Louis Sheldahl also made a major contribution to the study as Study Manager during the first quarter.

ABSTRACT (Total Study)

This study presents data—based upon a developed logic, task definitions, vehicle criteria, system analyses and design, and concepts of operation and implementation—with which the usefulness and cost of an entry flight research program can be evaluated.

The study defines 52 specific research tasks of value in developing operational lifting body systems, primarily for near-earth missions. Parametric design and performance data are evolved within a matrix of 5 vehicle sizes (with 1, 2, 4, 6 and 8 men) and 4 boosters (GLV, Titan III–2, Titan III–5 and Saturn IB) for all flight phases, from launch to landing. The design studies include vehicle arrangements, weight, aerodynamic heating and subsystem details. Systems integration analyses yield both design data, subsystem tradeoffs, and development and operations plans; and they lead, in turn, to cost effectiveness analyses which become the primary basis for vehicle and program selection.

A 25-foot long, 3-man vehicle weighing 12,342 pounds is selected for a research program of 9 manned (plus 2 unmanned) flights. This vehicle performs the maximum number of tasks and affords the highest research value per unit cost and the lowest cost per unit of payload in orbit; the estimated program cost is $1 billion. A detailed preliminary design of this vehicle is accomplished, including layout drawings and descriptions of each subsystem to identify available hardware as well as future options. Modifications for secondary research objectives—rendezvous and docking and supercircular entry—are considered.

The study also includes a brief examination of 2 smaller unmanned vehicles as alternate approaches to reduce cost.

CONTENTS

SUMMARY

This part of the report, "Study of the Influence of Size of a Manned Lifting Body on Entry Vehicle Research Potential and Cost," prepared under NASA Contract NAS 1-6209, describes special unmanned vehicles that could be used as possible alternatives for accomplishing lifting body research flight at low fiscal funding. Examination of the 52 candidate research tasks used for evaluation of manned entry vehicles indicated that 18 could be accomplished on unmanned vehicles. Although it was concluded that additional value could be gained if the unmanned tasks were revised along the lines of more automation, regrouping and combining, and close integration of flight data with ground simulators, this part of the study was exploratory only and was limited to already defined research tasks.

Two entry vehicles were evaluated for unmanned research missions: an 18-foot (5.5 m) long vehicle configured with all movable surfaces for horizontal landing, designated as G/0 and, a 9.67-foot (2.9 m) long vehicle to be air retrieved after hypersonic entry at about Mach 2, designated as F/0. Both of these entry vehicles are designed either for entry from low earth orbit using a Titan III core without transtage or for supercircular entry using a larger heat shield and certain equipment modifications and the Titan III-5 or Saturn IB. Entry velocities as high as 36 900 fps (11.2 km/sec) can be achieved with an F/0 entry vehicle and a Titan III-5 launch vehicle using close earth orbit trajectories. The G/0 vehicle can achieve 33 800 fps (10.3 km/sec) under the same conditions.

The F/0 vehicle, being severely limited in research weight and volume capability, was not analyzed for quantitative research value. The G/0 vehicle, on the other hand, has ample weight and volume for research equipment. When loaded on a four- and a seven-flight plan, it yielded values of 910 and 1363, respectively, compared to 2280 for the selected D/3 vehicle on a seven-flight plan. A total of 17 research tasks were loaded on the G/0 vehicle for seven flights. While total research value using the unmanned vehicle is a substantial portion of the D/3 value, many very important man-in-the-loop research tasks were necessarily eliminated.

Total research program costs are $185 million for the F/0 vehicle and $397 million for G/0 based on seven-flight plans. These compare to $850 million for the selected D/3 vehicle on seven flights. The 30 percent gain of the G/0 program over the D/3 in value per dollar has to be tempered by the limitation of the G/0 vehicle to do important flight mechanics and guidance/navigation research.

Finally, any alternate research program using an unmanned lifting entry vehicle should be closely integrated with the present air-launch programs (HL-10, M2-F2, SV-5P and X-15), the stability research aircraft (such as the F-106 VST), and piloted ground simulators. By closely interfacing such programs and increasing their scope, if necessary, some important objectives of manned lifting entry research can be attained.

I. INTRODUCTION

This part of the final report on a "Study of the Influence of Size of a Manned Lifting Body Entry Vehicle on Research Potential and Cost" describes the results of a special task on alternate approaches not specifically requested in the Contract Statement of Work.

As the magnitude of the cost of a manned research program was realized, it became evident that some consideration should be given to alternative methods of accomplishing lifting entry research but at a lower cost. The objective was to explore other approaches and possibly new research tasks that would permit continuance of lifting body entry vehicle development within more reasonable fiscal funding. This task was only exploratory and was worked at a very low effort.

The most obvious approach would have been to select a prototype of an operational logistics shuttle vehicle for entry research and thereby accomplish a double purpose with a single program. However, in the absence of any established mission specification, and because many of the experiments described in Part II do not require man, the alternate approach task concentrated on unmanned vehicles (similar to PRIME but larger). These vehicles would have the potential to significantly reduce program costs and increase the capability of achieving higher velocity entry with presently available launch vehicles.

II. ENTRY VEHICLE DESIGN

One alternate approach is to design an entry research vehicle (designated as G/0 to the smallest size that can maintain the complete aerodynamic configuration of the HL-10 including all movable surfaces. Dimensions become critical in the region of the fin trailing edges when practical allowances are made for structure and thermal protection. This vehicle would have 42.8 ft^3 (1.21 m^3) available for experimental equipment. The entry vehicle weight, with typical research task loading results in a 40 psf (196 kg/m^2) wing loading. This is well below the 55 psf (270 kg/m^2) required to simulate operational vehicles, thus providing the potential for many new experiments. A Titan III core without the transtage for single entry vehicle installation and a Saturn IB for multiple entry vehicle installation (LEM hangar) are potential launch vehicles for the G/0 entry vehicle.

The second alternate approach is to design an entry research vehicle, designated as F/0, for hypersonic and supersonic simulation only (down to Mach 2) as was done on the PRIME Program. In contrast to the PRIME vehicle, the F/0 allows for growth to supercircular heat shields, more measurements and more experiment equipment. Single or multiple installations using Titan III core without the transtage, Titan IIIC and Saturn IB are possible.

A. DESCRIPTION OF G/0 ENTRY VEHICLE

The G/0 entry vehicle is 18.0 feet (5.5 m) in length and has the same relative aerodynamic lines and control surface hinge points as the HL-10 "D" canopy configuration. The general arrangement of the subsystems is shown in figure 1. It is unmanned on all flights and is equipped to make horizontal landings after entry. The weight of this entry vehicle without adapter or deorbit motors is 4697 pounds (2.13 Mg). The launch weight is 5277 pounds (2.39 Mg) with adapter and deorbit motors. With a research equipment payload of 105 pounds (47.5 kg), the wing loading is 40 lb/ft^2 (195 kg/m^2). This payload is adequate to handle all of the unmanned research tasks identified in Part II on a 7 or 11 flight plan.

Although the 40-psf (195 kg/m^2) wing loading is considerably lower than the wing loading estimated for the full-scale manned applications, proper aerodynamic simulation of critical parameters (total heating, acceleration, dynamic pressure, etc.) will be possible through trajectory shaping, including steeper entry angles and variations in pitch and bank angle programs. In addition, results of many experiments which are obtained at one wing loading can be extrapolated to other wing loadings by means of analytic equations. Also, approach and landing simulation at typical full-scale wing loadings are planned for the HL-10 flight research program using an air-launched vehicle at Edwards Air

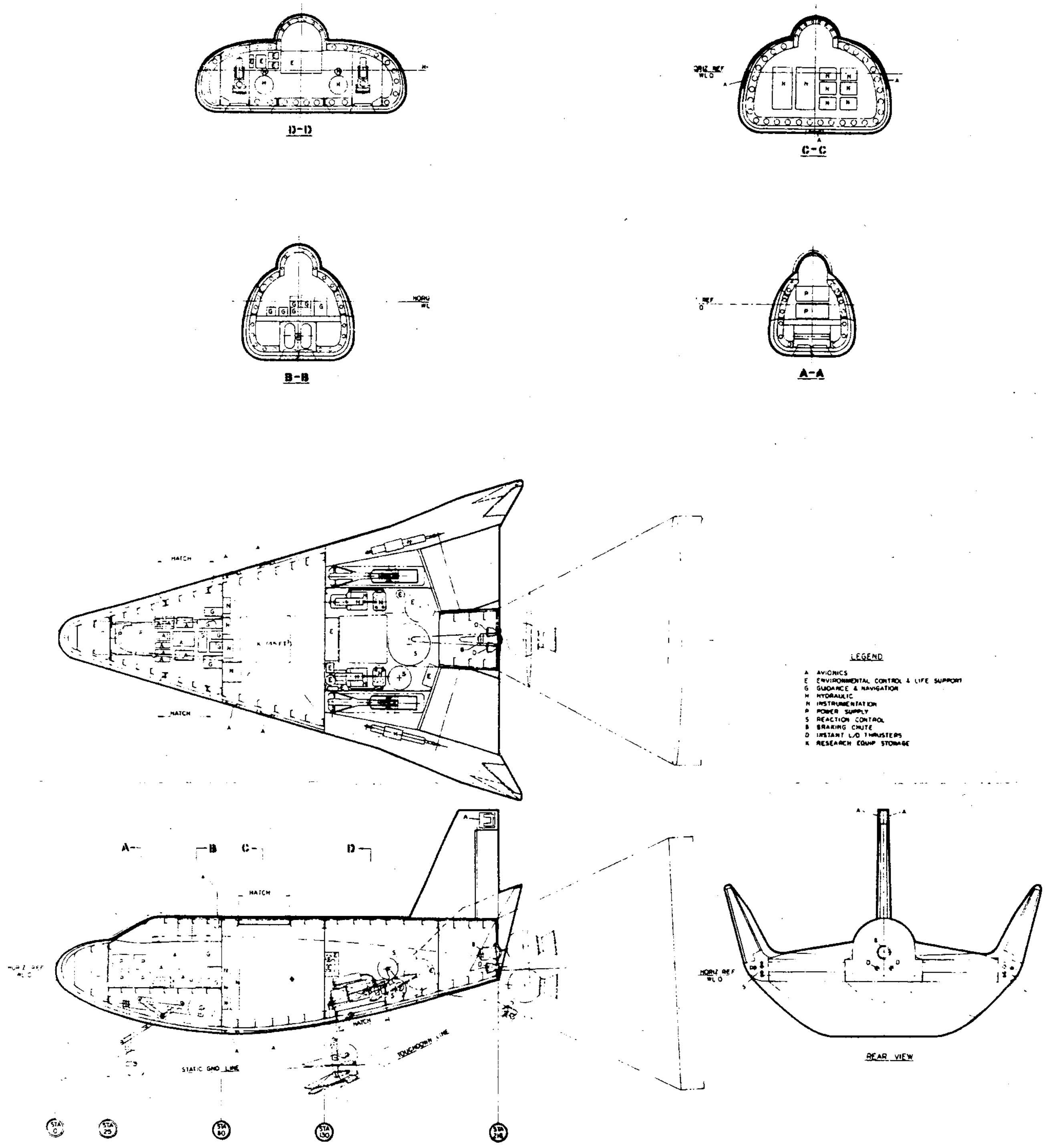

FIGURE 1. GENERAL ARRANGEMENT DRAWING--G/0 VEHICLE

Force Base. Since the payload capacity of the G/0 configuration is not limited by either volume or weight, the vehicle can be readily modified if additional experiments are defined or if ballast is required for any reason (including exact wing loading simulation). The G/0 subsystems are described briefly below.

1. Subsystems

Structure. - The entry vehicle structure, as in the D/3 design, is primarily welded 2219 T-6 aluminum alloy with major bulkheads forward of the nose wheel, aft of a simulated canopy, at the main landing gear attachment and forward of the elevon coves. Access hatches are on each side of the forward avionics and instrument compartment, atop a 45 ft^3 (1.3 m^3) midbody compartment and underneath the aft equipment. The G/0 vehicle is pressurized between the forward and the elevon cove bulkheads.

Heat shield. - The heat shield will be identical in material and construction to the D/3 vehicle, namely, removable all-ablator panels of ESA honeycomb bonded to fiber glass substrates and spray-on ESA on removable panels.

Electrical system. - Three silver-zinc batteries, with an independent supply for the hydraulic motor pumps, will provide power for the electrical system.

Environmental control. - Environmental control will be achieved by water evaporative cooling through conductive cold plates. There will be some heat sinks on the small equipment items.

Guidance, navigation and communications. - The G/0 vehicle utilizes the same primary guidance system as the D/3 which consists of an inertial platform, computer and horizon scanners (mounted in the adapter). Telemetry is transmitted by S-band and recorded on tape during the blackout. The terminal guidance and deorbit backup command are uhf and tracking is by C-band transponder. Automatic landing will be controlled from the ground through a uhf receiver on the entry vehicle decoder.

Instrumentation. - Provision is made for 1300 measurement channels. The subsystem includes remote multiplexers and central encoders.

Reaction control. - The subsystem is similar to that of the D/3 vehicle, namely, N_2 pressurized H_2O_2 with six thrustors. The H_2O_2 supply would also be used to feed the landing assist propulsion engine if it is required during the automatic landing procedure.

Surface controls. - As in the D/3 vehicle, this subsystem uses tandem hydraulic actuators for the two elevons and two rudders and electric actuators for the six trim surfaces.

Landing gear. - Skid wheels on the main gear and nose wheel are scaled down from the D/3 design. A braking chute is provided as part of the subsystem.

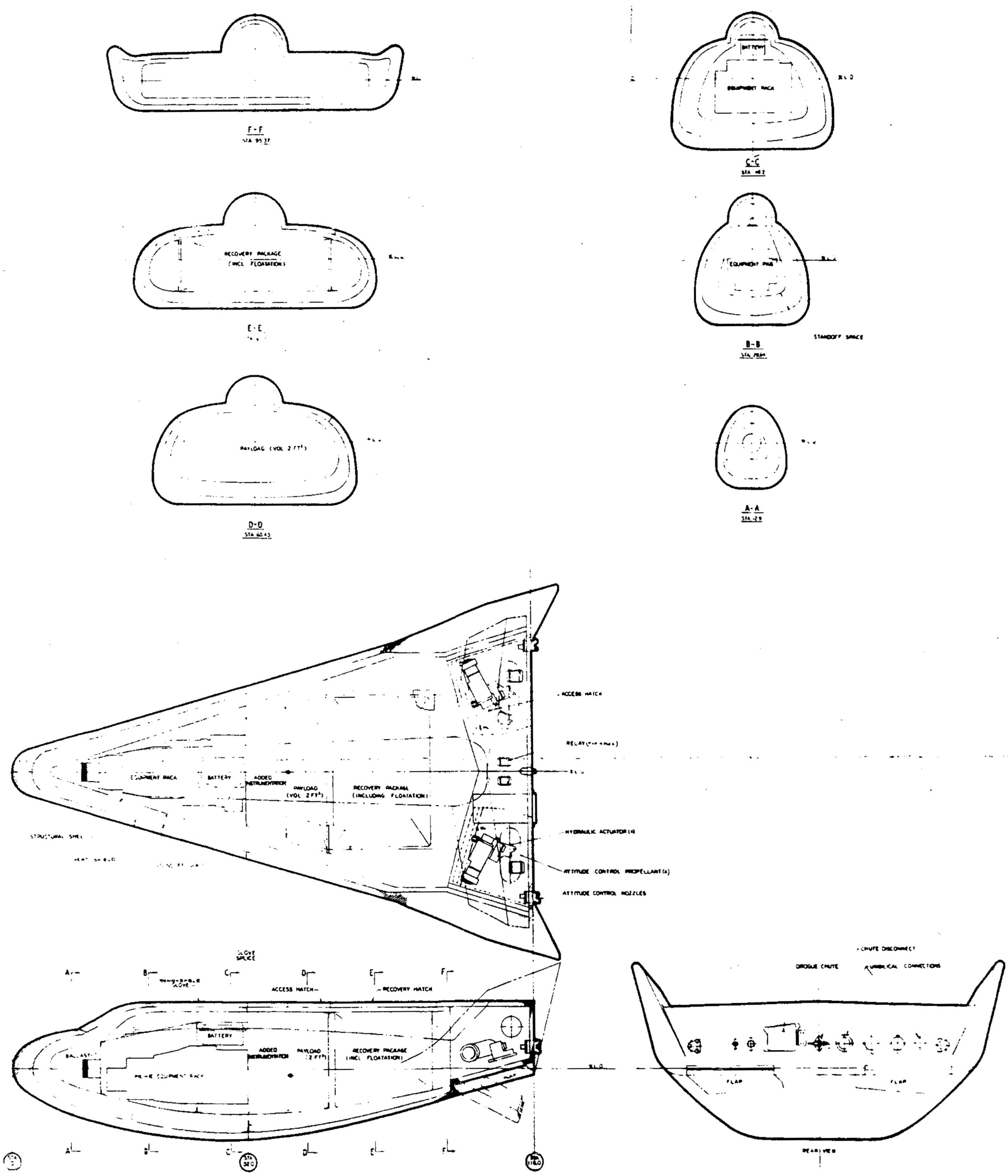

FIGURE 2. GENERAL ARRANGEMENT DRAWING--F/0 VEHICLE

Flight termination. - A lift disabling device will be provided to terminate the flight on command should the vehicle lose control on approaching the United States mainland.

B. DESCRIPTION OF F/0 VEHICLE FOR ORBITAL ENTRY

The F/0 vehicle, shown in figure 2, is a hypersonic (orbit to Mach 2) entry vehicle of minimum size containing 2 ft^3 (0.57 m^3) of volume for experiments and their power source and allowing for 4 inches (10 cm) of additional heat shield and/or insulation space for a possible superorbital entry research. The outer aerodynamic lines are modified at the aft end by raising the upper surface to simulate fully deflected trim surfaces. The additional volume resulting from the modification of the lines is used to house mechanical equipment such as the elevon actuation subsystem, the drogue ballute, etc.

Also, because test operations are conducted only on the back side of the L/D versus α curve, it has been assumed that the center fin would be totally ineffective and can be removed. The canopy and aft canopy fairing lines are retained. The total weight of the entry vehicle equipped with a heat shield for near orbital speeds is 1700 pounds (771 kg); the length is 9.67 feet (2.9 m). This entry vehicle is small enough to be mounted inside a conical shroud for launching. The primary recovery mode is air retrieval with water recovery as a backup. The volume allocated for recovery can accommodate an alternate paraglider system for landing on the land. Subsystems are briefly described below:

1. Subsystems

Structure. - The airframe is of a welded aluminum alloy construction and is vented during initial ascent and the later stages of entry. Equipment accessibility is gained by removing a 4 foot (1.2 m) nose glove and an upper surface access hatch.

Heat shield. - Removable ESA-honeycomb-fiber glass panels similar to the D/3 heat shield will be used. The nose glove will be a single replaceable unit.

Electrical system. - Silver-zinc batteries with a separate power system for the hydraulic pump motors will be used.

Environmental control. - Evaporative cooling (H_2O) with individual cold plates and heat sink mountings for smaller components will be used for environmental control.

Guidance navigation and communication. - The strapdown inertial reference system, computer and sensors of the PRIME SV-5D vehicle were selected for the F/0 configuration. The vhf transmitter, C-band transponder and vhf receiver of the PRIME vehicle are included in the design.

Instrumentation and telemetry. - Allowance is made for 600 measurements using PRIME commutators, subcarrier oscillators and tape recorder components.

Reaction control. - A nitrogen cold gas system is used for the 3/4 orbit mission.

Surface controls. - Only the lower elevons are movable. Actuation is by integral hydraulic actuator packages with self-contained motor pump and accumulator.

Recovery system. - A single canopy parachute with center extension for air retrieval will be contained in the aft bay. A ballute-type drogue device will be deployed at about Mach 2 and will extract the main parachute. A backup water recovery system, consisting of a flotation cell and water recovery aids, is included in this installation.

C. SPECIAL SUBSYSTEMS FOR SUPERCIRCULAR ENTRY

The F/0 vehicle is an attractive research tool for solving supercircular entry problems associated with the maneuvering class of entry vehicles. As discussed in the previous section, ample space between the outer lines and the load-carrying structure has been allotted to accommodate a heat shield for entry velocities in the 40 000 fps (12.2 km/sec) to 65 000 fps (19.8 km/sec) velocity range. Because of higher elevon hinge moments and actuation rates, bigger hydraulic actuators will be required for supercircular entry. Corridor constraints of supercircular entry impose requirements for a guidance and navigation system similar to that recommended for the HL-10 D/3 vehicle, namely, the IN-16 IMU and D103H computer units. Substitution of this system would increase weight by 75 pounds (34 kg) and may be volume critical. Because of the very high launch vehicle investment involved in the supercircular missions, it is expected that measurements will have to increase by at least 300, doubling the instrumentation weight. Corresponding increases in battery and recovery chute weights are also required.

D. ENTRY VEHICLE WEIGHTS

Weights for the basic F/0 and G/0 entry vehicles are summarized in table 1. Also shown in this table are the estimated weights for an F/0 vehicle configured for supercircular entry at 40 000 fps (12.2 km/sec). The adapter and deorbit weights are not shown for the supercircular F/0 entry vehicle because these weights are included in a special velocity stage.

[redacted]

TABLE 1

ALTERNATE VEHICLE WEIGHT BREAKDOWN

Vehicle designation	F/0		F/0		G/0	
Vehicle length	9.67 ft (2.9 m)		9.67 ft (2.9 m)		18.0 ft (5.5 m)	
Entry velocity	26 000 fps (7.9 km/sec)		40 000 fps (11.2 km/sec)		26 000 fps (7.9 km/sec)	
Weight units	lb	Mg	lb	Mg	lb	Mg
Total vehicle weight	(1699)	(7.70)	(2196)	(9.95)	(4697)	(21.3)
Heat shield	536	2.43	806	3.66	1512	6.85
Structure	287	1.30	300	1.36	1176	5.32
Electrical system	33	0.15	45	0.20	380	1.72
Environmental control	20	0.09	25	0.11	110	0.50
Guidance, navigation and communication	70	0.32	145	0.66	218	0.99
Instrumentation	163	0.74	163	0.74	414	1.88
Reaction control	20	0.09	24	0.11	70	0.32
Surface control	46	0.21	69	0.31	416	1.89
Landing gear	--	--	--	--	211	0.96
Recovery system	234	1.06	285	1.29	--	--
Landing assist propulsion	--	--	--	--	85	0.39
Experiment equipment	34	0.15	34	0.15	105	0.48
Ballast	256	1.16	300	1.36	--	--
Total adapter	--	--	--	--	(580)	(2.63)
Structural	--	--	--	--	336	1.52
Deorbit	--	--	--	--	202	0.92
Miscellaneous	--	--	--	--	42	0.19
Launch weight	1699	7.70	2196	9.95	5277	23.9

[redacted]

III. LAUNCH VEHICLE POSSIBILITIES

Two types of missions have been treated for the alternate approaches: entry from low earth orbit with both F/0 and G/0 type vehicles, and supercircular entry with both vehicles. The launch vehicle candidates considered for orbital entry flight missions are as follows:

Entry vehicle	Entry vehicles/launch vehicle	Launch vehicle, payloads Primary	Piggyback
F/0	1	T-III core w/o transtage	T-III-5
F/0	2	T-III-2	T-III-5
F/0	3	T-III-2	Saturn IB
F/0	4	T-III-2	Saturn IB
G/0	1	T-III core w/o transtage	Saturn IB
G/0	2	Saturn IB	Saturn IB
G/0	3	Saturn IB	Saturn IB

Supercircular entry may be accomplished in several ways:

(1) By velocity stages in near-earth trajectories

(2) By highly elliptical trajectories which could approach millions of miles apogee

(3) By piggyback on an Apollo lunar mission in which the entry vehicle and a service module would be released into an earth-return trajectory.

The latter two techniques involve long mission times and require expensive guidance and mission support modules. The near-earth supercircular mission is inefficient in achieving velocity, however. Table 2 compares entry velocity performance for various launch vehicles for injection of the F/0 and G/0 entry vehicles. The D/2 manned entry vehicle, recommended for supercircular entry research (see Part VII), is also compared in this table.

TABLE 2

ENTRY VELOCITY POTENTIAL

Launch vehicle	Entry vehicle					
	Near earth trajectories			Highly elliptical trajectories		
	F/0	G/0	D/2	F/0	G/0	D/2
T-III-2	35.4K (10.8)	31.5K (9.6)	<26.0K (7.9)	39.5K (12.0)	35.2K (10.7)	28.0K (8.5)
T-III-5	36.9K (11.2)	33.8K (10.3)	28.2K (8.6)	41.2K (12.6)	37.8K (11.5)	30.3K (9.2)
Saturn IB	35.4K (10.8)	33.2K (10.1)	28.9K (8.8)	39.5K (12.0)	37.1K (11.2)	32.8K (10.0)
Saturn V	39.2K (11.9)	38.7K (11.8)	39.3K* (12.0)	43.9K (13.4)	43.0K (13.1)	45.5K* (13.9)

Velocity indicated in fps (km/sec)
*Two-stage velocity module required.

It should be noted that multiple entry vehicle launches in the supercircular trajectories are more difficult than the orbital cases since all the vehicles launched on the single launch vehicle must enter at approximately the same time. If the objective is to approach 40 000 fps (12.2 km/sec), only 500 fps (0.15 km/sec) is gained in reducing the payload from the G/0 to the F/0 vehicle. On the other hand, a gain of 4000 fps (1.2 km/sec) is obtained using the F/0 rather than the G/0 in the 30 to 35K fps (9.1 to 10.7 km/sec) range, using the Titan III-2 launch vehicle.

One method of significantly reducing program cost of an entry research program is to share the launch operations with other programs. However, the true cost of such an approach is difficult to estimate without specific flights identified and without many design and operational factors examined in detail. Moreover, if the entry research program is considered a secondary mission on any given launch, the probability of achieving the entry research objectives may be significantly reduced.

Several piggyback techniques for launching single and multiple entry vehicles are suggested in the sketches of figure 3. Separation of the entry vehicle from the storage position, their positioning in orbit and their deorbit sequence are problem areas to be further investigated.

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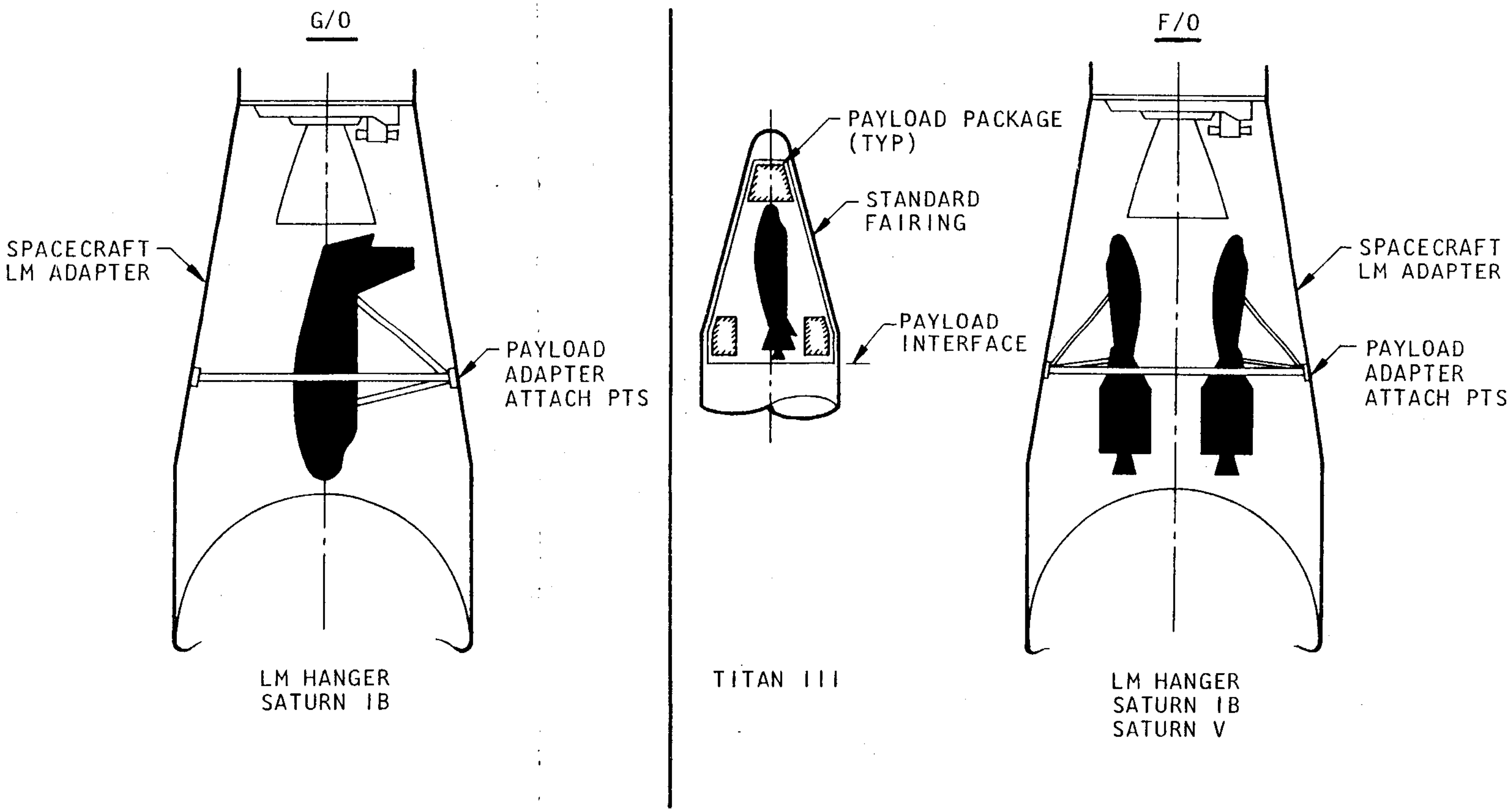

FIGURE 3. PIGGYBACK POSSIBILITIES

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IV. RESEARCH PROGRAM POSSIBILITIES

Two research program approaches present themselves. First, research tasks associated with a return from earth orbit can be conducted within the limitations of unmanned flight. Out of the 52 research tasks defined for this study, 18 do not require man and are not constrained by manned tasks. This is a severe limitation on value and excludes eight critical flight mechanics experiments and five of the most important guidance tasks. However, many of these excluded experiments could be reoriented to unmanned flights to gain some very significant research data. Increased scope in simulator programs and the air-launch program could also enhance the research potential of the unmanned vehicles.

The second approach of supercircular entry research would concentrate on hypersonic entry phases in which man is less involved. Fully automatic guidance and energy management is expected to be the primary mode for supercircular entry. Heat shield performance, primary guidance and navigation performance, and hypersonic aerodynamic characteristics would be among the potential research tasks for the superorbital research vehicles. Further evaluation of the research potential of the F/0 and G/0 entry vehicles would require a new listing of research tasks especially matched to their performance and flight profiles.

V. PROGRAM VALUE AND COSTS

Development and operational (research flight) programs have been derived for the G/0 and F/0 entry vehicle approaches and costs determined by the COCOM cost model. Four, 7 and 11 flight research programs have been costed for both the F/0 and G/0 entry vehicle for comparison with the similar programs of the D/3 manned entry vehicle. Research value has been determined only for the G/0 vehicle because of the undeterminable reduction in value for experiments applied to the F/0 vehicle. Severe experiment weight and volume limitations, scale effects on aerodynamic results and the Mach 2 lower speed limit all contribute to this reduction.

A. ALTERNATIVE APPROACH PROGRAMS

The objective of the alternative approach program is to yield the maximum research results within the constraints of the smaller sized, unmanned F/0 and G/0 entry vehicles. Also, in order to reduce cost, the total program span is reduced by taking the normal risks associated with unmanned space programs.

1. F/0 Entry Vehicle Plan

The F/0 vehicle can be launched by several techniques:

(1) Titan III core without transtage; entry vehicle in conical shroud; launch from Cape Kennedy into 3/4 orbit with recovery by air retrieval near Hawaii. Westerly launch from Point Arguello and recovery at Kwajalein is a possible alternative.

(2) Launch several entry vehicles with a Titan III core (without transtage) or Saturn IB; release entry vehicles into orbit and command deorbit to successive entries spaced at least one orbit apart; entry vehicles to be recovered by air retrieval at one primary and one alternate site.

Single entry vehicle launchings with the Titan III core (no transtage) have been selected for costing. Both the 7- and 11-flight programs were established with identical development phases. Characteristics of the F/0 development program are:

(1) Four-month final definition phase

(2) All components qualified 18 months after final definition phase go-ahead

(3) First research flight scheduled 25 months after go-ahead

(4) One completely equipped entry vehicle, one structural entry vehicle and two boiler plate parachute drop vehicles to be fabricated for test.

(5) Entry vehicles and refurbishment requirements are:

Entry flights (no.)	4	7	11
Total entry vehicles built	5	5	6
Refurbishments (no.)	0	3	6

(6) Two sets of GSE (factory and launch site) are required.

Note that the 1700-pound (771-kg) entry vehicle is well below the Titan III payload-in-orbit capability for single entry vehicle launches. The Titan III core without transtage was selected for cost evaluation:

(1) To allow for weight growth and potential velocity stages beyond the payload capability of smaller launch vehicles such as Atlas

(2) To retain the capability to launch the F/0 vehicles in pairs

(3) To lessen program impact if at some later date, superorbital entry tests are desired using a Titan III-5.

Use of the Atlas launch vehicle could reduce cost somewhat if these growth factors were discounted. The F/0 vehicle schedule plan is shown in figure 4.

2. G/0 Vehicle Plan

The G/0 vehicle is launched by a Titan III core (no transtage) from Cape Kennedy. An alternate scheme, not costed, would be Saturn IB piggyback in the LEM hangar. The Titan III core will insert the entry vehicle into a 3/4 orbit, retro, enter and land at the NASA FRC (Edwards AFB) using automatic landing techniques.

As in the case of the F/0 vehicle program, the development programs for the 7- and 11-flight programs are considered identical. The G/0 vehicle will require the same automatic landing system as proposed for the unmanned vehicles of the A through E series.

Characteristics of the G/0 development program are:

(1) Five-month Final Definition Phase.

(2) All components qualified within 20 months after final definition phase go-ahead.

(3) First research flight 25 months after go-ahead.

(4) One completely equipped entry vehicle and two structural test vehicles (one for static load and heating and one for dynamic loads) will be used during development.

(5) Evaluation of the automatic landing system will be initially carried out by the present HL-10 air-launch vehicle at the NASA FRC.

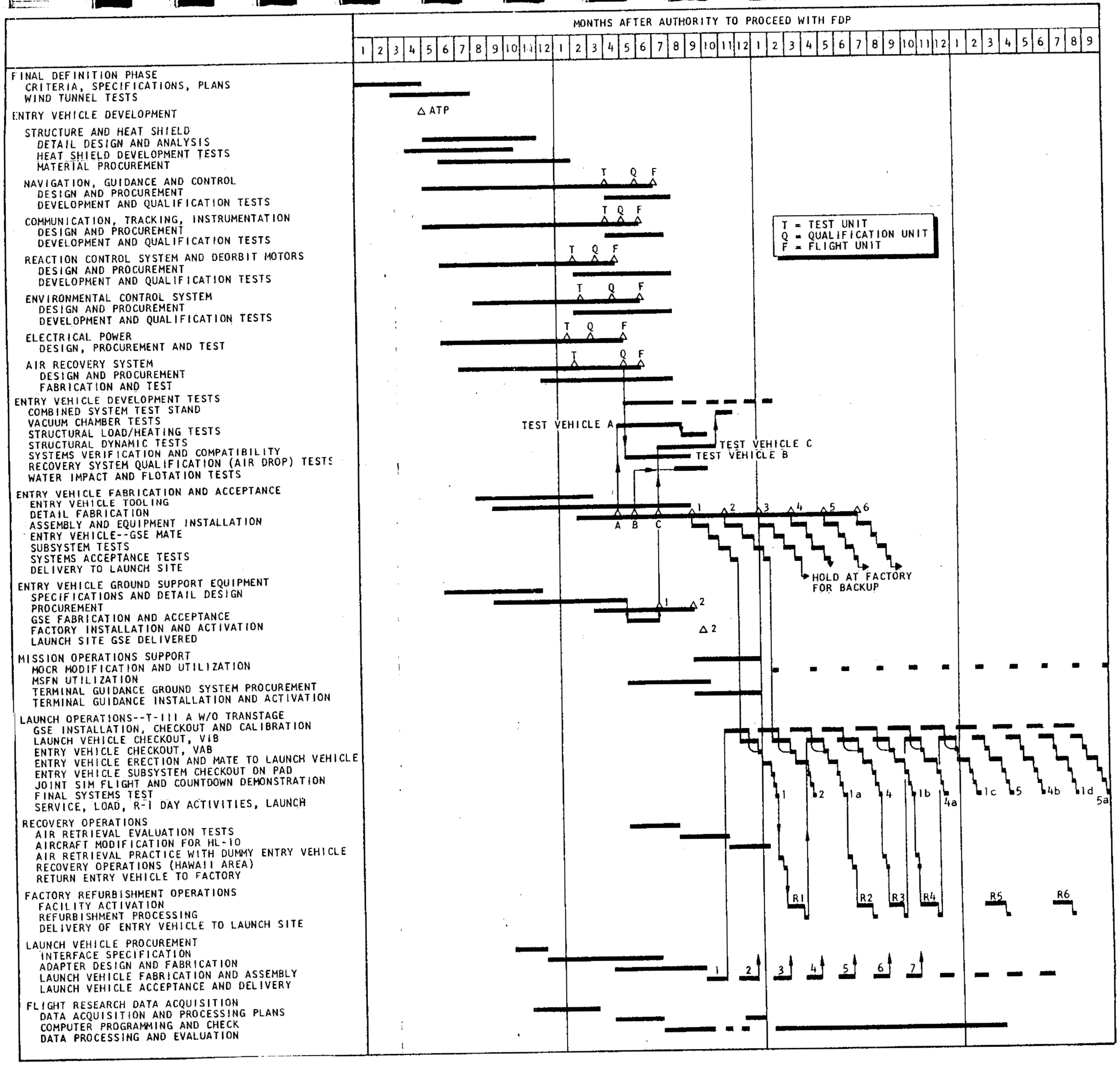

FIGURE 4. ALTERNATE APPROACH PLAN--F/0 VEHICLE, SEVEN AND ELEVEN FLIGHTS

(6) Entry vehicle and refurbishment requirements are:

Entry flights (no.)	4	7	11
Total entry vehicles built	5	5	6
Refurbishments (no.)	0	3	6

(7) Two complete sets of GSE (factory and launch site) are required.

The overall scope of the development and flight operations program is shown on the schedule of figure 5.

B. RESEARCH FLIGHT PROGRAMMING--G/0 VEHICLE

To gain some insight into the research potential of the unmanned G/0 vehicle, the 52 research tasks were reviewed for candidates that could be loaded in the G/0 vehicle for up to seven flights. Table 3 lists tasks excluded because of man's requirement, tasks excluded by prerequisite constraints on tasks requiring man, and the remaining candidate tasks. These tasks were then loaded on four- and seven-flight plans and the research value determined by the linear programming technique for optimum flight loading as described in Part VI of this report. The four-flight program (entry conditions C, B, F and G, sequentially) allowed a total loading of 17 research tasks. Sequence of entry conditions for the seven-flight program was selected as C-C-D-F-F-G-H. Table 4 shows the loading and values for the four- and seven-flight programs. The values of 910 and 1363 for the four- and seven-flight programs may be compared to a value of 2280 for the manned D/3 vehicle on a seven-flight program.

Note that a number of the tasks excluded because of the manned requirement could be redefined for at least partial accomplishment on unmanned flights. However, this would necessarily involve a reassessment of their relative research value. Redefinition of the research tasks for the alternative vehicle approaches and a revision of the flight loading optimization would be a worthwhile follow-on study activity.

TABLE 3

RESEARCH TASK CANDIDATES FOR G/0 VEHICLES

Rank	Task	Task description	Excluded due to: Man requirement	Excluded due to: Precedences	Can be loaded on G/0
1	SM-1	Ablative heat shield performance evaluation			x
2	FM-8	Measure heat rate distribution			x
3	FM-3	Evaluate flying qualities	x		

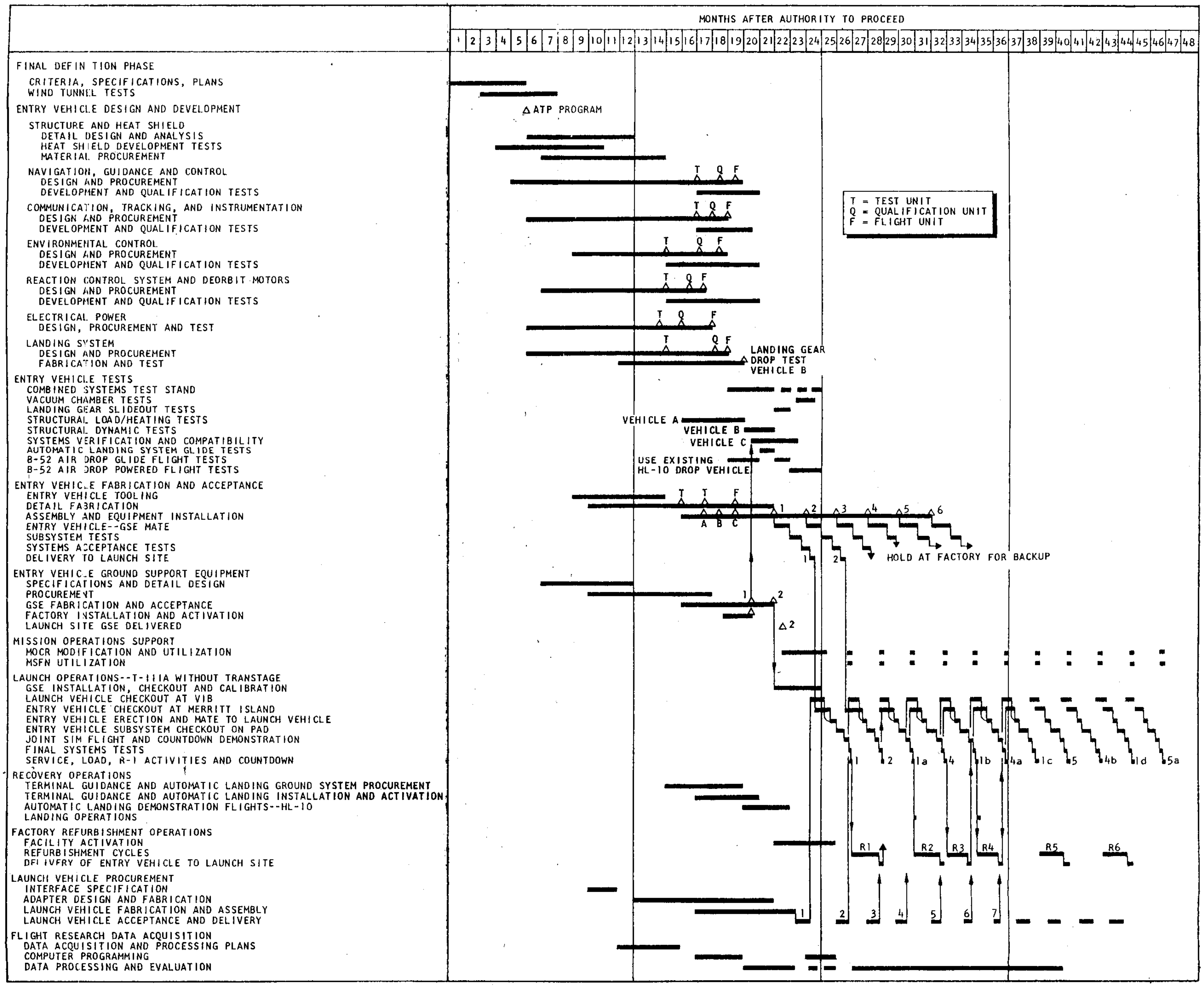

FIGURE 5. ALTERNATE APPROACH PLAN--G/0 VEHICLE, SEVEN AND ELEVEN FLIGHTS

TABLE 3. - Continued

RESEARCH TASK CANDIDATES FOR G/0 VEHICLES

Rank	Task	Task description	Excluded due to: Man requirement	Excluded due to: Precedences	Can be loaded on G/0
4	FM-2	Evaluate aero characteristics	x		
5	FM-7	Measure pressure distribution			x
6	GN-4	Inertial navigation error propagation		x	
7	FM-4	Measure control effectiveness	x		
8	GN-5	Hypersonic entry guidance techniques	x		
9	FM-13	Ablation effects in hypersonic aero performance		x	
10	EV-2	Evaluate reuse capability and refurbishment			x
11	GN-1	Primary navigation and guidance performance	x		
12	FC-1	Flight control system evaluation	x		
13	SM-6	Movable surface heat shield evaluation	x		
14	FM-5	Measure elevon shock interaction		x	
15	SM-2	Ablative heat shield joints			x
16	SM-8	Refurbishable heat shield demonstration			x
17	FM-17	Hypersonic boundary layer transition	x		
18	GN-6	Terminal navigation and guidance techniques	x		
19	FM-14	Viscous effects on lift and drag		x	
20	GN-2	Backup guidance performance		x	
21	SM-17	Ascent static and dynamic response			x
22	SM-7	Ablator ascent heating/ cold soak			x
23	SM-5	Insulation cavity pressure			x
24	SM-9	Radiation heat shield	x		
25	SM-3	Ablator heat shields			x

TABLE 3. - Concluded

RESEARCH TASK CANDIDATES FOR G/0 VEHICLES

Rank	Task	Task description	Excluded due to: Man requirement	Excluded due to: Precedences	Can be loaded on G/0
26	GN-3	Autonomous orbital navigation	x		
27	FM-6	Measure entry stability and control	x		
28	FM-12	Boundary layer survey			x
29	FC-2	Adaptive flight control system	x		
30	FC-3	Digital flight control mechanization	x		
31	GN-7	Air data measurements		x	
32	SM-14	After heat effects			x
33	FC-4	Flight control actuation	x		
34	FM-15	Measure plasma thermophysics			x
35	PP-3	Landing assist propulsion	x		
36	HF-2	Crew biomedical evaluation	x		
37	SM-10	Radiative and radiative to ablative joints		x	
38	SM-12	Ablator overcoat on radiative heat shield		x	
39	PP-2	Jet exhaust/vehicle boundary layer	x		
40	SM-13	Heat shield instrumentation sensors			x
41	PP-1	Jet impingement effects	x		
42	SM-11	Active and passive structural cooling	x		
43	SM-16	Catalytic wall experiments			x
44	AV-2	Satellite communication experiments	x		
45	HF-1	Pilot control/landing of entry vehicle after orbit	x		
46	FM-16	Effects of electrophilic fluid injection			x
47	SM-15	Transpiration cooling system	x		
48	FM-9	Measure gas cap radiation			x
49	AV-1	Antenna window material test			x
50	FM-18	Use of ventral antenna to alleviate blackout	x		
51	SM-18	In-flight heat shield repair	x		
52	FM-19	Synergetic maneuver without propulsion	x		
		Total	26	8	18

TABLE 4

FLIGHT LOADING OF RESEARCH TASKS ON G/0 VEHICLE

Research task	Loaded value	Flights loaded 1	2	3	4
SM-1	213	x	x		
FM-8	62	x	x	x	
FM-7	53	x	x	x	
SM-2	50			x	
SM-7	75		x		
FM-12	66	x	x	x	
SM-5	80	x	x	x	
SM-17	71	x	x	x	
SM-3	51			x	x
FM-15	50	x		x	x
SM-14	50		x		x
SM-13	33	x	x	x	x
SM-16	29	x		x	
FM-16	16	x	x	x	
AV-1	11	x	x	x	

Total value = 910

Research task	Loaded value	Flights loaded 1	2	3	4	5	6	7
SM-1	213	x		x				
FM-8	161	x	x	x	x	x		
FM-7	138	x	x	x	x	x		
EV-2	94					x	x	x
SM-2	107				x	x		
SM-8	79					x	x	x
SM-7	75			x				
FM-12	65	x	x	x				
SM-5	79	x	x		x			
SM-17	74	x		x	x			
SM-3	72		x	x	x	x	x	x
FM-15	50	x	x	x				
SM-14	50	x		x				
SM-13	42	x	x	x	x	x	x	x
SM-16	29	x	x					
FM-16	24	x	x	x	x	x		
AV-1	11	x	x	x				

Total value = 1363

The number of experiments in three major categories (e.g., confirmation/verification, technology advance, pure research) for four- and seven-flight plans with the G/0 vehicle and 7- and 11-flight plans with the D/3 vehicle are summarized in table 5.

TABLE 5

FLIGHT LOADING SUMMARY

Category	Flights D/3 11	D/3 7	G/0 4	G/0 7
Confirmation/verification	27	24	9	10
Technology advance	20	17	4	5
Pure research	3	3	2	2
Total	51	44	15	17

C. PROGRAM COSTS

Total program costs for the HL-10 G/0 and F/0 unmanned configurations were calculated by the same method as the cost for the D/3 configuration, by using the Coincident Cost Model (COCOM).

For these two designs three operational flight regimes were priced. Specifically, they included a 4-flight program, a 7-flight program and an 11-flight program. The annual procurement, launch and refurbishment schedules are shown in table 6.

Significant inputs to the nonrecurring (development) costs are provided by tables 7 and 8 for the F/0 and G/0 vehicles, respectively.

TABLE 6

ANNUAL PROCUREMENT F/0 AND G/0 VEHICLES

F/0 entry research programs											
Number of flights	4			7				11			
Year of delivery	1970	1971	Total	1970	1971	1972	Total	1970	1971	1972	Total
Entry vehicle deliveries	2	3	5	2	3	0	5	2	3	1	6
Adapter deliveries	2	3	5	2	5	1	8	2	5	5	12
Launches	1	3	4	1	4	2	7	1	4	6	11
Refurbishments	0	0	0	0	2	1	3	0	2	4	6
G/0 entry research programs											
Number of flights	4			7				11			
Year of delivery	1970	1971	Total	1970	1971	1972	Total	1970	1971	1972	Total
Entry vehicle deliveries	2	3	5	2	3	0	5	2	3	1	6
Adapter deliveries	2	3	5	2	5	1	8	2	5	5	12
Launches	1	3	4	1	4	2	7	1	4	6	11
Refurbishments	0	0	0	0	2	1	3	0	2	4	6

TABLE 7

F/0 VEHICLE NONRECURRING COST INPUTS

Subsystem nomenclature	Weight, lb	Tooling rate capacity per yr	Ground test quantity*	Flight test quantity*
Structure	285	4	3.0	2.0
Heat shield	536	4	2.5	1.0
Surface control	46	4	5.0	1.0
Reaction control	20	4	4.0	1.0
Guidance and communication	70	4	2.0	1.0
Instrumentation	163	4	2.0	1.0
Research equipment	--	Excluded by direction		
Indirect vision	0	Provided for potential application		
Environmental	20	4	4.0	1.0
Electrical	35	4	4.0	1.0
Instant L/D propulsion	0	Not applicable		
Landing gear	0	Not applicable		
Emergency chutes	234	4	4.0	2.0
Crew provisions	0	Not applicable		
Display panel	0	Not applicable		
Adapter structure	0	Not applicable		
Adapter, environmental	0	Provided for potential application		
Adapter, electrical	0	Provided for potential application		
Adapter, deorbit propulsion	0	Not applicable		
Adapter, miscellaneous	0	Not applicable		

NOTE: Quantity represents equivalent units, e.g., three-half subsystems = 1.5.

TABLE 8

G/0 VEHICLE NONRECURRING COST INPUTS

Subsystem nomenclature	Weight, lb	Tooling rate capacity per yr	Ground test quantity*	Flight test quantity*
Structure	1176	4	3.0	2.0
Heat shield	1512	4	2.5	1.0
Surface control	416	4	5.0	1.0
Reaction control	70	4	4.0	1.0
Guidance and communication	218	4	2.0	1.0
Instrumentation	414	4	2.0	1.0
Research equipment	105	Excluded by direction		
Indirect vision	0	Provided for potential application		
Environmental	145	4	4.0	1.0
Electrical	380	4	4.0	1.0
Instant L/D propulsion	85	4	3.0	0.0
Landing gear	211	4	4.0	0.0
Emergency chutes	0	Not applicable		
Crew provisions	0	Not applicable		
Display panel	0	Not applicable		
Adapter structure	336	4	3.0	0.0
Adapter, environmental	0	Provided for potential application		
Adapter, electrical	0	Provided for potential application		
Adapter, deorbit propulsion	202	4	6.0	0.0
Adapter, miscellaneous	42	4	3.0	0.0

NOTE: Quantity represents equivalent units, e.g., three-half subsystems = 1.5.

The F/0 vehicle is uniquely configured as compared to the G/0 and D/3 vehicles. Since it nearly approximates the size of the PRIME entry vehicle, the assumption has been made that the F/0 would use the same subsystem components as PRIME. In areas requiring more power, for example, more of the same batteries would be used. As a result, realistic cost savings are feasible, especially for the nonrecurring (development) portion.

Some cost benefit accrues for the F/0 in the recurring (operational) sector as well. Sustaining engineering has a lesser burden to carry; the follow-on usage of proven components lessens the probability of design changes. Also, though the Titan III core is the launch vehicle priced, a smaller launch vehicle represents a reasonable alternate and consequent savings. However, the choice of the Titan III lies in its ability to accept a substantially heavier (than the basic F/0) payload, thus permitting future missions (supervelocity entry) without interface with another family of boosters.

Table 9 summarizes the nonrecurring and recurring costs for the F/0 and G/0 for the 4-, 7- and 11-flight programs, respectively.

TABLE 9

ALTERNATIVE APPROACH PROGRAM COST SUMMARY

Entry vehicle	F/0			G/0		
Number of research flights	4	7	11	4	7	11
Nonrecurring (development)	70 932 704			207 833 600		
Management	3 377 748			9 896 840		
Design	13 952 338			76 329 728		
Initial tooling	4 907 614	Same as previous column	Same as previous column	17 132 396	Same as previous column	Same as previous column
Tool maintenance	736 141			2 569 858		
Initial GSE	20 374 744			52 949 312		
GSE maintenance	2 546 843			6 618 664		
Ground testing	7 481 091			16 147 650		
Spacecraft spares	1 725 100			3 549 897		
Flight testing	13 766 180			19 686 376		
Mission support	2 064 926			2 952 955		
Nonrecurring (facilities)	1 355 522			2 812 872		
Total nonrecurring, $	72 288 224	72 288 224	72 288 224	210 646 464	210 646 464	210 646 464
Recurring (operational)	68 456 544	111 716 928	167 115 744	120 095 056	184 872 000	254 539 520
Management	3 874 898	6 323 599	9 459 382	6 797 834	10 464 452	14 407 898
Sustaining engineering	5 301 888	7 562 165	7 562 165	29 005 288	41 370 696	41 370 696
Spacecraft	16 026 974	16 697 036	19 946 648	35 475 056	37 040 120	44 271 280
Tool maintenance	250 426	397 767	379 767	874 233	1 325 761	1 325 761
Additional GSE	0	1 633 857	4 310 269	0	3 790 645	10 000 082
GSE maintenance	1 039 684	1 661 869	1 732 407	2 701 903	4 295 072	4 458 723
Launch operations	1 712 886	2 899 836	4 436 327	3 761 706	6 368 394	9 742 714
Recovery operations	1 027 731	1 739 901	2 661 796	2 257 024	3 821 037	5 845 629
Refurbishment operations	0	2 678 355	4 943 829	0	6 255 303	11 433 600
Mission control operations	4 556 406	9 327 214	16 205 672	4 556 406	9 327 214	16 205 672
Launch vehicles	34 665 664	60 813 368	95 477 552	34 665 664	60 813 368	95 477 552
Recurring (facilities)	412 715	875 908	1 658 291	774 922	1 724 260	3 254 135
Total recurring, $	68 869 284	112 592 832	168 774 016	120 869 968	186 596 256	257 793 632
Total program cost*, $	141 157 472	184 881 056	241 062 240	331 516 432	397 243 720	468 440 096

*Does not include procurement of research task equipment.

VI. EVALUATION OF PROPOSED ALTERNATIVE APPROACHES

The F/0 vehicle is quite limited when considering its capability to accomplish research as specified in the 52 candidate research tasks of table 3. This mainly comes about because of the limited weight and volume available for experiments, the limited number of telemetered measurements available, the uncertainty in aerodynamic performance results due to the small scale and the lower flight limit of Mach 2. Although redefinition of research tasks tailored to the F/0 vehicle is beyond the scope of this brief study, it appears that such a group of tasks could allow the F/0 vehicle to be a valuable research tool in important areas like hypersonic aerodynamics, heat shield performance and reuse. The F/0 vehicle also has considerable potential for supercircular entry research because of its small size, its adaptability to multiple installations and piggyback arrangements possible on large launch vehicles such as Saturn IB and Saturn V.

In contrast to the F/0, the G/0 entry vehicle can be compared directly with the larger D/3 vehicle since it can fly essentially the same unmanned mission as the D/3, and its size is much nearer to full scale. Cost, research value, and value/cost comparisons between the G/0 and D/3 vehicles are made in figure 6. Note that, for a seven-flight program, the G/0 vehicle is less than half the cost of an equivalent D/3 program but achieves more than half the research value. The research value per dollar is then substantially higher for the G/0 vehicle (about 30%). It must be emphasized that although there is an apparent gain in research potential per dollar, all the man-in-loop research tasks are sacrificed with the G/0 approach and growth to manned mission capability is impossible. As mentioned in the Introduction, concurrent follow-on to the present air launch programs at FRC (HL-10, M2-F2, SV-5P and X-15), plus use of variable stability aircraft such as the F-106 VST, could accomplish some of the manned research objectives. Piloted ground simulation could also be utilized to a much greater extent than is presently the case to solve the hypersonic problems.

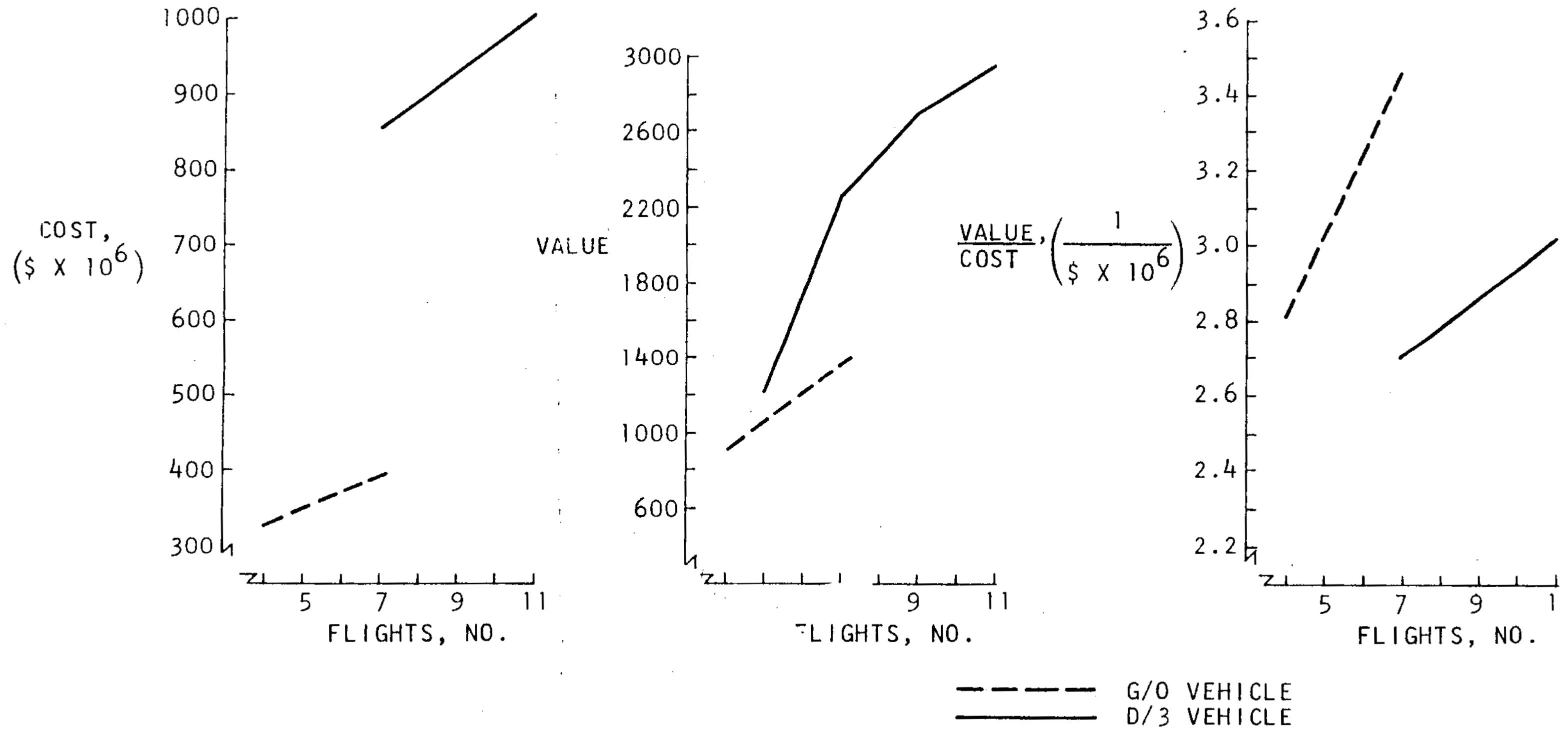

FIGURE 6. ALTERNATE APPROACH CHARACTERISTICS SUMMARY

VII. CONCLUSIONS AND RECOMMENDATIONS

Some very tentative conclusions drawn from the study of alternate approaches are:

(1) While the F/0 vehicle is limited in orbital entry research potential, the cost would be 1/6 that of a D/3 vehicle program.

(2) The F/0 vehicle appears attractive when applied to supercircular entry research in the 30- to 35K-fps (9.1- to 10.7-km/sec) velocity range.

(3) The G/0 vehicle will yield a higher value per dollar than the D/3 in orbital entry research but at the same time excludes a number of critical flight mechanics and guidance experiments.

(4) Multiple entry vehicle launches on Titan III or Saturn IB launch vehicles may have considerable cost saving potential provided mission reliability can be maintained.

Further evaluation of these and other alternates is recommended before any final decisions are made as to the usefulness of these approaches. Further investigation into more extensive exploitation of existing lifting entry and simulation programs as they relate to research accomplishment is also recommended.